SYSTEMIC CLIMATE RISK

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European Systemic Risk Board
Ieke van den Burg Prize
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LAYOUT

- Introduction
- Objective
- Framework
- Literature review
- Data
- Results
- Robustness
- Conclusion
- Appendix

INTRODUCTION

Mark Carney: Breaking the tragedy of the horizon – climate change and financial stability

Speech by Mr Mark Carney, Governor of the Bank of England and Chairman of the Financial Stability Board, at Lloyd's of London, London, 29 September 2015.

Source: https://www.bis.org/review/r151009a.pdf

Climate Change Is Called Threat to U.S. Economy

The New York Times

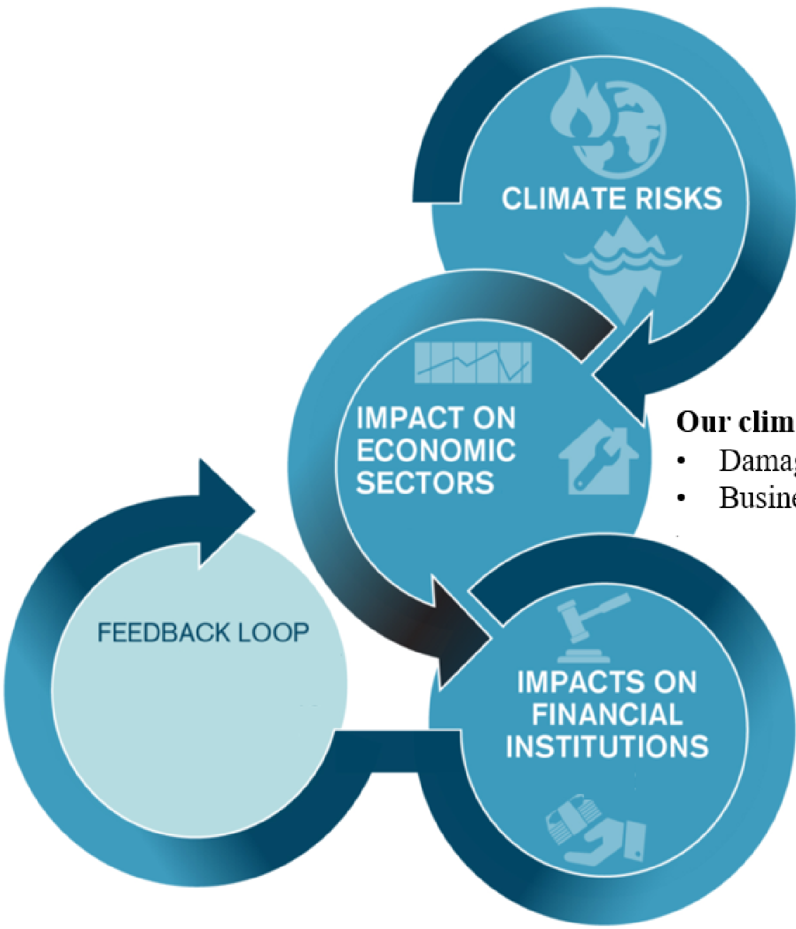
The New York Times
Late Edition - Final
Business/Financial, Saturday, December 18, 2021

By Alan Rappeport

WASHINGTON -- Federal regulators warned for the first time in an annual report to Congress on Friday that climate change was an "emerging threat" to the U.S. financial system, laying out how the costs associated with more hurricanes, wildfires and floods caused by global warming could lead to a cascade of damage throughout the economy.

INTRODUCTION

Climate risks and financial stability



Transition risks
- Technological changes
- Policy shifts
- Changes in consumer preferences

Physical risks
- Chronic (e.g., sea level rise)
- Acute (e.g., hurricanes)

Our climate risk factors capture:
- Damages to property
- Business interruption, effect on business income

Our framework studies:
- Direct exposure to credit and market risks
- Amplification through interconnections, correlated exposures, and fire sales. (Duarte & Eisenbach, 2021)

Source: Financial Stability Oversight Council

OBJECTIVE

- Design a **market-based framework** to examine the effects of climate risks on the financial sector:

  – First-round effects: decrease in value of financial portfolios, credit worthiness of borrowers, etc.

  – Second-round effects: climate shocks spread to other institutions through the financial network.

  => Broad definition of « contagion »: Exposure to common shocks, spillovers and pure contagion (Masson, 1998)

- **Key questions**:
  – Which are the most vulnerable financial institutions (FIs)?
  – Can climate risks generate contagion effects among FIs?
  – Can FIs and policymakers undertake actions to mitigate systemic climate risk?

THE FRAMEWORK – INTUITION

- **The economic rationale** : climate risks should lead to a repricing of securities (Carney, 2015) held by financial institutions.

- **Purpose** : assess whether climate shocks are reflected into asset prices and are already propagating to/among financial institutions.

- The framework complements the forward-looking approach of climate stress tests (e.g., Battiston et al., 2017; Vermeulen et al., 2018; ECB, 2022), based on long-term scenarios, but subject to uncertainty (Barnett et al., 2020).

THE FRAMEWORK – SUMMARY

A/ DESIGN INPUTS

STEP 1
Systemic risk measure

STEP 2
Climate risk factors

B/ TEST FOR SYSTEMIC CLIMATE RISK

STEP 3
Two-pass test procedure

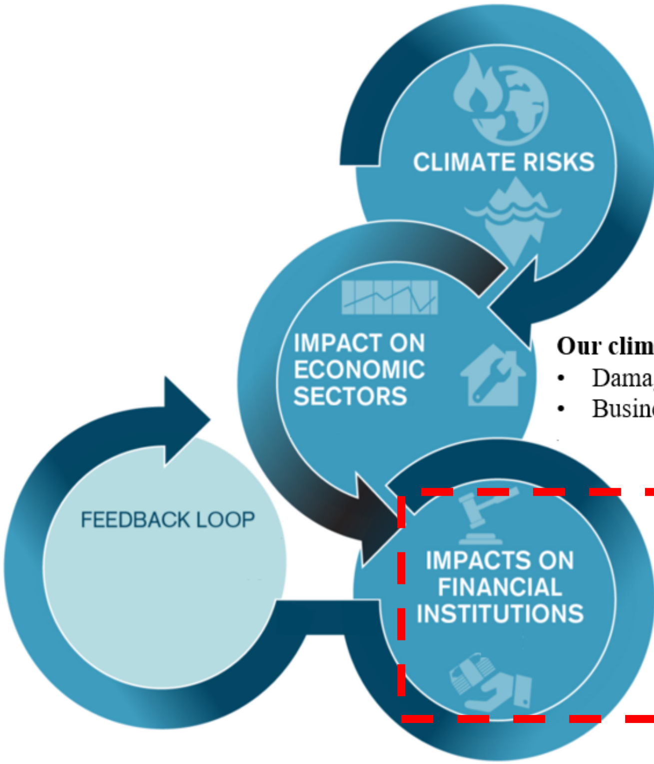
C/ ACTIONS TO MITIGATE SYSTEMIC CLIMATE RISK

STEP 4
Determinants of FIs exposure to climate risks

THE FRAMEWORK – STEP I

- **Construct a "market-based" systemic risk measure:**

Climate risks and financial stability



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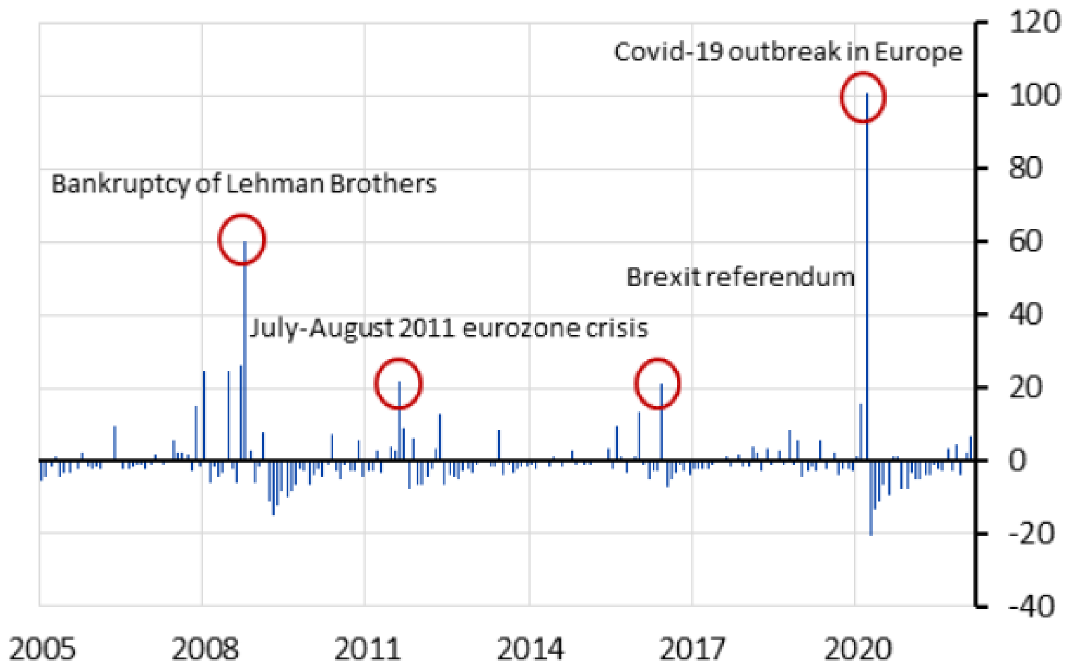
THE FRAMEWORK – STEP I

- **Construct a “market-based” systemic risk measure:**
  - It captures 2 elements of systemic risk: (a) individual tail risks and (b) contagion effects.
  - Dynamically estimate the Value-at-Risk (VaR) of each FIs and extract covariations (using a PCA analysis).
  - Related indicators: Adams et al. (2014), Adrian and Brunnermeier (2016), and Kelly and Jiang (2014).
  - Advantage: the indicator can be used to distinguish (a) the first and (b) second-round effects of climate risks.

THE FRAMEWORK – STEP I

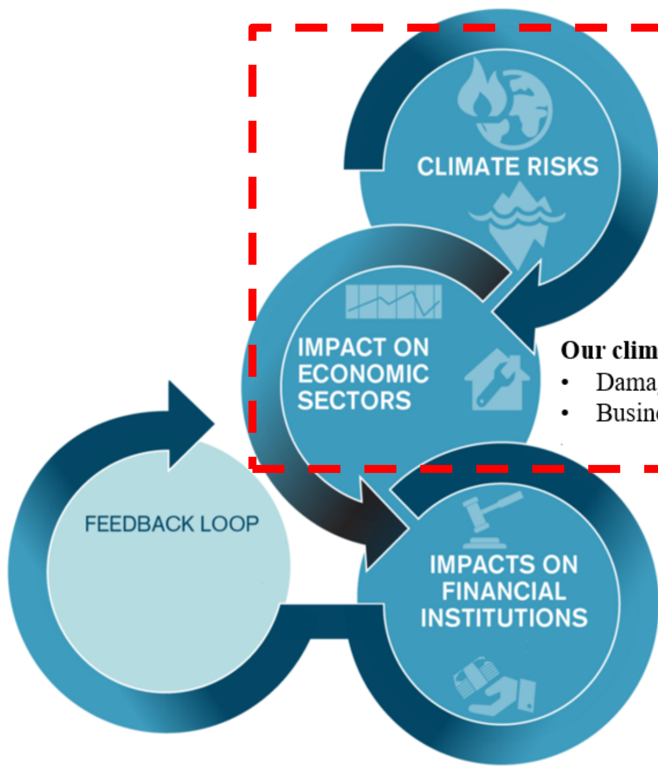
- **Systemic risk measure:**
  - The indicator represents the first principal component $\widehat{\Omega}_1$ accounting for the common variations in the VaR of FIs.



THE FRAMEWORK – STEP II

- **Build "market-based" climate risk factors for NFC:**

Climate risks and financial stability



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Quentin Moreau (HKUST)

THE FRAMEWORK – STEP II

- **Build "market-based" climate risk factors for NFC:**
  - The factors capture the effect of climate shocks on the value of non-financial firms.
  - We disentangle between (a) transition and (b) physical risks.
  - Long-short factor mimicking portfolios (e.g., Fama & French, 1993) based on climate characteristics.
  - At each point in time, we sort firms into brown and green portfolios and compute the difference of returns between the portfolios.

THE FRAMEWORK – STEP II

- **Factor reaction to exogenous climate shocks:**

Natural Disasters			
Quantile	Climate shock indicator value	Conditional average	Physical factor returns (%)
0,05	0	Inferior to	0,12
0,1	0		0,12
0,9	1910000	Superior to	-0,62
0,95	3593752		-0,83
Abnormal temperatures			
Quantile	Climate shock indicator value	Conditional average	Transition factor returns (%)
0,05	-0,29	Inferior to	0,34
0,1	0,37		0,22
0,9	2,47	Superior to	-0,79
0,95	2,91		-1,14
Climate news			
Quantile	Climate shock indicator value	Conditional average	Transition factor returns (%)
0,05	-0,71	Inferior to	1,98
0,1	-0,64		1,70
0,9	0,78	Superior to	-0,08
0,95	0,96		-0,75

THE FRAMEWORK – STEP II

▪ "Extreme" climate risk factors

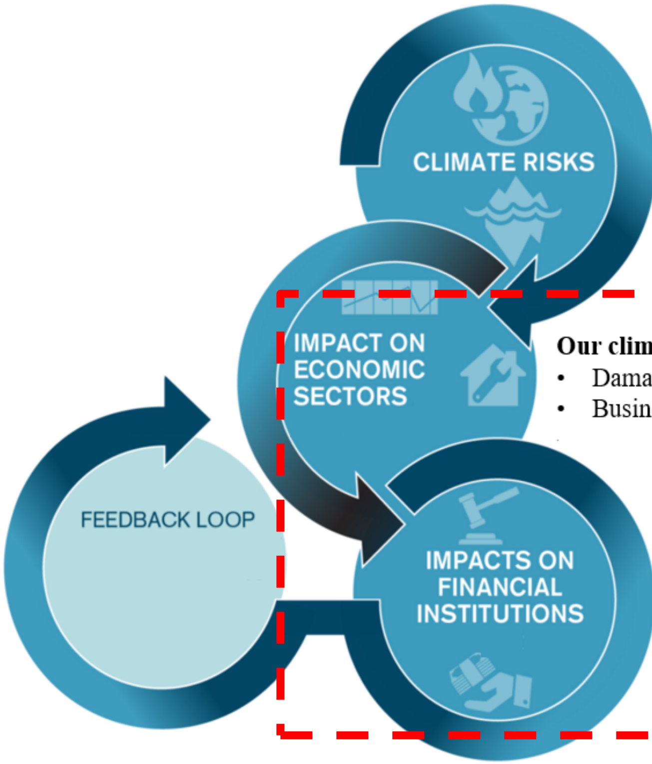
Finally, we derive a « tail risk » version of these factors based on <u>dynamic VaR.</u>

- for consistency with the first step (systemic risk indicator)
- to reflect the expected impact of extreme climate shocks on non-financial companies
- to account for uncertainty in the pricing of green and brown firms

THE FRAMEWORK – STEP III

- **Design a two-pass procedure to detect systemic climate risks**

Climate risks and financial stability



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Source: Financial Stability Oversight Council

THE FRAMEWORK – STEP III

- First-round effects: Estimate individual FIs' exposures to climate risks
  - Time-series regression of the variations in individual FI VaR on climate risk factors.
  - Aggregate results using the mean-group estimator (Pesaran, 1995)

- Second-round effects: Design a two-pass procedure to detect systemic climate risks
  - Time-series regression of the variations in systemic risk on climate risk factors.
  - Cross-sectional regression of financial institutions' contributions to systemic risk on financial institutions' exposures to climate risks.

THE FRAMEWORK – STEP IV

- **Determinants of FIs' climate risk exposures:**
  - Financial characteristics.
  - Environmental and governance features.
  - Indirect carbon emissions (Scope 3), originating from the holding of securities and loans by financial institutions.
  - Ownership structure (institutional / non-institutional)
  - Climate disclosure and adaptation measures.

LITERATURE REVIEW (I)

- We contribute to **3 strands of literature**:

1. **The integration of climate risks into asset prices** (e.g., Ardia et al., 2020; Bolton and Kacperczyk, 2021; Choi et al., 2020; Alok et al., 2020; Hong et al., 2019; Kruttli et al., 2021)

➢ We propose a flexible framework to assess whether extreme climate risks are reflected in the tail risk of equity markets.

2. **The effect of climate risks on financial stability** (e.g., Aevoae et al., 2022; Alessi et al., 2021; Anginer et al., 2018; Jung et al., 2021; Ojea-Ferreiro et al., 2022)

➢ Our framework focuses on tail risk dependence among FIs, allowing us to capture the potential second-round effects of climate risks.

LITERATURE REVIEW (II)

- We contribute to **3 strands of literature**:

  3. **The link between (i) climate risks and (ii) environmental characteristics and disclosure** (e.g., Dhaliwal et al., 2011; Ilhan et al., 2021; Li et al., 2020; Sautner et al., 2020)

➢ First to study the <u>determinants of **market-based** measure of climate risks</u> and adaptation measures.

DATA (I)

- Data goes from 2005 to 2022 for members of the European Union (+ UK, Switzerland and Norway).
- 371 active stocks of financial institutions (Banks, life insurers, non-life insurers, financial services, real estate - REIS and REITs).
- Thousands of active and dead *non-financial* European stocks to build climate risk factors.

DATA (II)

For all companies, we retrieve:

- **Financial data**
  - Datastream Refinitiv: prices including dividends, market capitalizations, book values of equity, cash holdings, total assets, incomes, net sales, and fixed assets
- **Environmental data**
  - Datastream Refinitiv: Carbon emissions (Scope 1 & 2)
  - Carbone 4: Carbon emissions *induced by portfolio holdings* (Scope 3) for financial institutions
  - Trucost: Main physical risk scores
  - ISS-ESG/Carbone4: Alternative physical risk scores
  - Bloomberg/Datastream: Climate disclosure, ESG characteristics
- **Institutional ownership data**
  - Securities Holdings Statistics (SHS-S) database: FIs holders by sector

  (Percentage of ownership by banks, insurance, and pension funds : items S_122, S_128, and S_129)

DATA (III)

- Control variables that can help explain variations in systemic risk:

  - **Systematic risk factors based on equity market data (Harvey et al, 2016)**
    - Hou-Xue-Zhang, Kenneth-French, Pastor-Stambaugh, AQR data libraries : size, value, momentum, expected growth, liquidity, quality-minus-junk, etc.

    => They capture « different set of bad times » (Ang, 2014), such as small and value firm distress (Fama and French, 2015); momentum crashes (Daniel and Moskowitz, 2016)

  - **Other macroeconomic and financial factors (Lettau et al., 2008; Adrian et al, 2016)**
    - Bloomberg, ECB, Eurostat, Fred: default premium, interbank market liquidity, yield curve spread, economic sentiment, etc.

RESULTS – INDIVIDUAL EXPOSURES TO CLIMATE RISKS

- "Climate" Exposure CoVaR measure that incorporates extreme climate risks as potential stress factors for financial institutions.

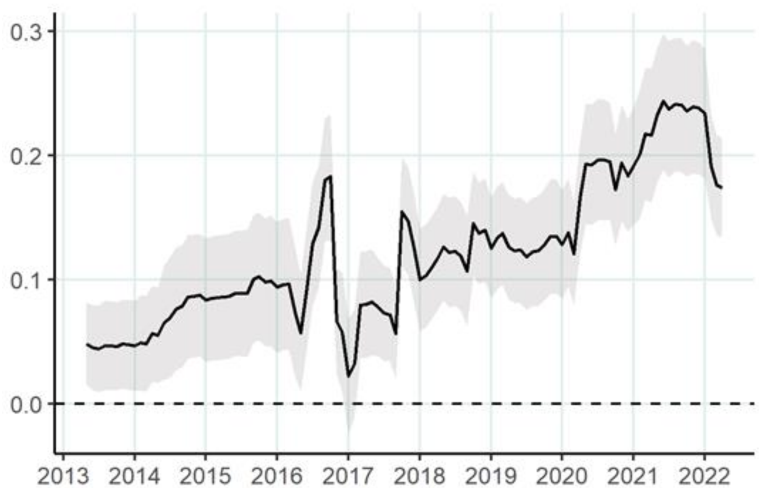
- Run individual time-series regressions

$$\underbrace{\widehat{\Delta \mathrm{VaR}}_{i,t}}_{\text{Dynamic VaR of FIs}} = \alpha + \underbrace{\beta_{BMG} BMG_t}_{\text{Transition risk factor}} + \underbrace{\beta_{VMS} VMS_t}_{\text{Physical risk factor}} + \sum_{i=1}^{I} \beta_{f_i} f_{i,t} + \varepsilon_t$$

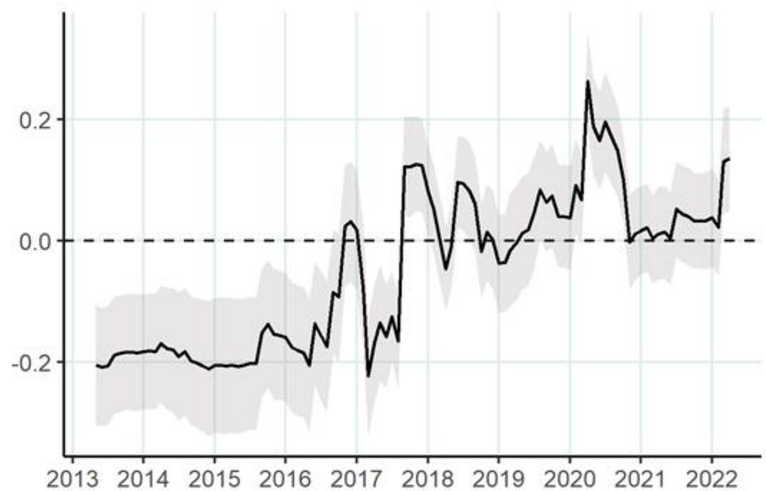
Market risk factors

- Aggregate results using the mean-group estimator (Pesaran, 1995)

Transition risk (β_{BMG})



Physical risk (β_{VMS})



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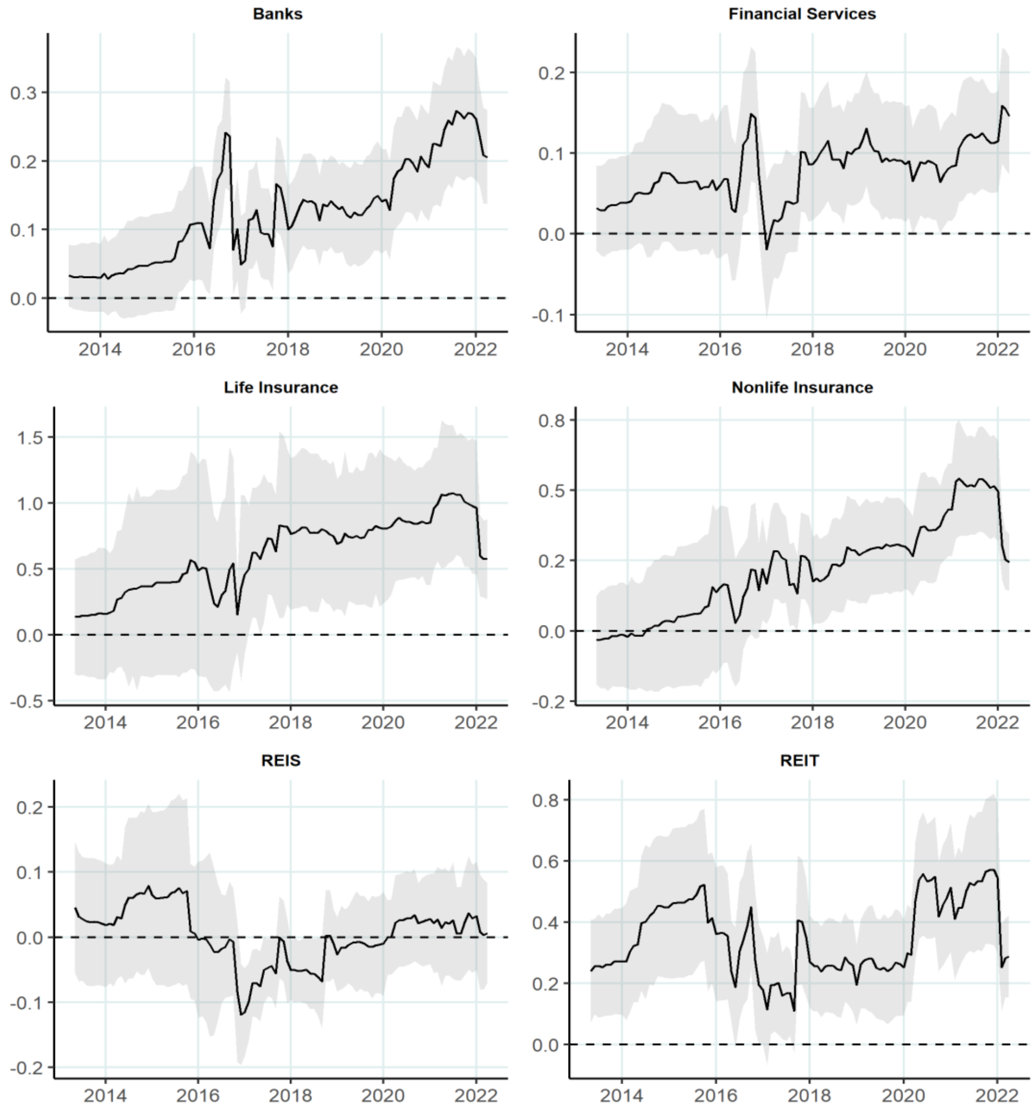
RESULTS – TRANSITION RISK BY FINANCIAL INDUSTRY



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RESULTS – EFFECT OF CLIMATE RISKS ON SYSTEMIC RISK (I)

- The two-pass test procedure:

1. **Time series regression** : are climate risks associated with tail risk dependence among FIs?

$$\underbrace{\widehat{\Omega}_{1,t}}_{\text{Covariations in tail risk among FIs (1st PC)}} = \alpha + \beta_{BMG} BMG_t + \beta_{VMS} VMS_t + \sum_{i=1}^{I} \beta_{f_i} f_{i,t} + \varepsilon_t$$

Covariations in tail risk among FIs (1st PC)

2. **Cross-sectional regression :** Do FIs most exposed to climate risks contribute more to global risk?

$$\underbrace{\widehat{X}_{1,j}}_{\text{Contribution of each FIs to tail risk dependence (weights on the 1st PC)}} = \alpha + \gamma_{BMG} \hat{\beta}_{BMG,j} + \gamma_{VMS} \hat{\beta}_{VMS,j} + \sum_{i=1}^{I} \gamma_{f_i} \hat{\beta}_{f_{i,j}} + \varepsilon_j$$

Contribution of each FIs to tail risk dependence (weights on the 1st PC)

RESULTS – EFFECT OF CLIMATE RISKS ON SYSTEMIC RISK (II)

- Transition risk affects systemic risk, while physical risk does not.
- The magnitude of the effect of transition risk is moderate (0.06 st. dev).
- Results are robust to alternative sets of systematic and market stress factors.

In the time series

VARIABLES	(1) $\widehat{\Omega}_1$	(2) $\widehat{\Omega}_1$
BMG	1.392**	0.898*
	(0.545)	(0.486)
VMS	-0.063	-1.237
	(1.755)	(1.850)
MKT	3.272***	3.178***
	(0.373)	(0.423)
SMB	11.396***	11.202***
	(3.356)	(3.253)
HML	6.118***	6.014***
	(1.603)	(1.822)
RMW		-0.988
		(3.388)
CMA		0.325
		(0.552)
WML		0.623***
		(0.231)
Constant	-0.057	-0.062
	(0.305)	(0.296)
Observations	207	207
R-squared	0.820	0.829
Adjusted R-squared	0.816	0.822

In the cross-section

VARIABLES	(5) $\hat{X}_1$	(6) $\hat{X}_1$
$\hat{\beta}_{BMG}$	0.010***	0.011***
	(0.002)	(0.003)
$\hat{\beta}_{VMS}$	-0.001	-0.001
	(0.002)	(0.002)
$\hat{\beta}_{MKT}$	0.010	0.008
	(0.012)	(0.015)
$\hat{\beta}_{SMB}$	0.003***	0.003***
	(0.001)	(0.002)
$\hat{\beta}_{HML}$	0.002	0.004
	(0.002)	(0.005)
$\hat{\beta}_{RMW}$		0.001
		(0.004)
$\hat{\beta}_{CMA}$		0.004
		(0.011)
$\hat{\beta}_{WML}$		0.016
		(0.010)
Observations	371	371
R-squared	0.309	0.321
Adjusted R-squared	0.239	0.245
FE : Country	Yes	Yes
FE : Industry	Yes	Yes

RESULTS – CHARACTERISTICS CORRELATED WITH TRANSITION RISK

- FIs with high transition risk exposure have higher market capitalizations (ECB, 2022).
- FIs with lower Scope3 emissions, reliable emission data/emission reduction pathways, and with long-term orientation are less exposed to transition risk.

VARIABLES	(1) $\hat{\beta}_{BMG_{avg}}$	(2) $\hat{\beta}_{BMG_{avg}}$	(3) $\hat{\beta}_{BMG_{avg}}$	(4) $\hat{\beta}_{BMG_t}$	(5) $\hat{\beta}_{BMG_t}$	(6) $\hat{\beta}_{BMG_t}$	(7) $\hat{\beta}_{BMG_t}$	(8) $\hat{\beta}_{BMG_t}$
Beta (t-1)	0.0439***	0.0234**	-0.00373	-0.300	-0.431*	-0.439**	-0.0931	-0.0921
	(0.0113)	(0.0112)	(0.0716)	(0.205)	(0.226)	(0.189)	(0.0973)	(0.0846)
LogMarketValue (t-1)	0.0236***	0.0254***	0.0746***	0.200	-0.0532	0.0269	0.0312	-0.0201
	(0.00265)	(0.00274)	(0.0161)	(0.175)	(0.185)	(0.211)	(0.0748)	(0.0645)
Cash (t-1)	-0.259***	-0.229***	-0.194	0.528	0.0251	-0.409	-0.184	0.125
	(0.0566)	(0.0629)	(0.238)	(0.762)	(1.095)	(0.774)	(0.334)	(0.343)
NetIncome (t-1)	0.252***	0.155*	-0.178	-0.928	-1.523	-0.471	-0.239	0.110
	(0.0885)	(0.0884)	(0.249)	(0.590)	(0.943)	(0.829)	(0.261)	(0.223)
MtoB (t-1)	0.00620	0.00268	-0.0432**	-0.0266	0.378**	0.251	-0.0331	-0.0576
	(0.00449)	(0.00443)	(0.0203)	(0.0930)	(0.152)	(0.172)	(0.0386)	(0.0500)
LowScope3intensity (t-1)				-0.118*				
				(0.0639)				
VerifiedScope3 (t-1)					-0.297*			
					(0.153)			
ReductionTargetReached (t-1)						-0.137**		
						(0.0678)		
Board LT incentives (t-1)							-0.0723*	
							(0.0412)	
Institutionalownership(t-1)								-0.363***
								(0.114)
Constant	-0.108***	-0.251***	-0.248	-0.693	-0.693	0.669	0.235	0.660
	(0.0170)	(0.0784)	(0.201)	(1.421)	(1.421)	(1.695)	(0.478)	(0.418)
Observations	5,992	5,992	3,245	925	715	699	3,245	2,222
R-squared	0.036	0.161	0.134	0.652	0.631	0.716	0.541	0.706
Adjusted R-squared	0.036	0.157	0.122	0.570	0.575	0.645	0.481	0.649
Country Fixed Effects	No	Yes	Yes					
Industry Fixed Effects	No	Yes	Yes					
Institution Fixed Effects	No	No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	No	No	Yes	Yes	Yes	Yes	Yes	Yes

RESULTS – CHARACTERISTICS CORRELATED WITH PHYSICAL RISK

- FIs with high physical risk levels have lower market capitalizations.

VARIABLES	(1) $\hat{\beta}_{VMS_{avg}}$	(2) $\hat{\beta}_{VMS_{avg}}$	(3) $\hat{\beta}_{VMS_t}$	(4) $\hat{\beta}_{VMS_t}$	(5) $\hat{\beta}_{VMS_t}$
Beta (t-1)	0.299***	0.327***	0.433*	0.0898	-0.387
	(0.0538)	(0.0496)	(0.224)	(0.319)	(0.293)
LogMarketValue (t-1)	-0.0934***	-0.0544***	-0.0527	-0.434**	-0.434*
	(0.0106)	(0.0109)	(0.0424)	(0.186)	(0.224)
Cash (t-1)	-0.334*	0.521**	-0.0367	0.0485	0.688
	(0.201)	(0.226)	(0.588)	(0.519)	(0.545)
NetIncome (t-1)	0.265	0.439	0.211	0.396	-0.285
	(0.319)	(0.323)	(0.768)	(0.675)	(0.824)
MtoB (t-1)	-0.0513***	-0.0310*	-0.0160	0.113	0.243**
	(0.0189)	(0.0178)	(0.0787)	(0.0964)	(0.102)
Board LT incentives (t-1)				-0.0175	
				(0.159)	
Institutional ownership (t-1)					-0.0908
					(0.324)
Constant	0.310***	1.665***	0.595	2.917**	2.996*
	(0.0627)	(0.226)	(0.618)	(1.280)	(1.533)
Observations	5,992	5,992	3,245	3,245	2,222
R-squared	0.020	0.217	0.139	0.504	0.644
Adjusted R-squared	0.019	0.213	0.127	0.439	0.575
Country Fixed Effects	No	Yes	Yes		
Industry Fixed Effects	No	Yes	Yes		
Institution Fixed Effects	No	No	No	Yes	Yes
Year Fixed Effects	No	No	Yes	Yes	Yes

RESULTS – ADAPTATION MEASURES TO TRANSITION RISK

- FIs with higher exposure to transition risk engage in selective ESG/climate disclosure (e.g., Management Discussion and Analysis section of annual reports, allowing communication in a flexible manner; Brown et al., 2021).
- Potential suspicion of greenwashing (Campbell et al., 2014; Yu et al., 2020).
- Column (5) : Evidence against regulatory capture concerns (see also Schneider et al., 2023).

VARIABLES	(1) Integrated Strategy	(2) Discuss ClimateRisk	(3) Environmental Disclosure Score	(4) Log CarbonOffsets	(5) Policy Engagement
$\hat{\beta}_{BMG}$ (t-1)	0.246***	0.323***	-0.0261**	0.413*	-0.397**
	(0.0940)	(0.111)	(0.0127)	(0.245)	(0.201)
Constant	-2.297***	-1.067	0.183*	-4.796	-1.397
	(0.673)	(0.688)	(0.103)	(3.836)	(1.114)
Observations	1,136	1,292	978	335	812
R-squared			0.709	0.618	
Adjusted R-squared			0.635	0.339	
Controls	Yes	Yes	Yes	Yes	Yes
Country-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Industry-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes

RESULTS – ADAPTATION MEASURES TO PHYSICAL RISK

- As most investors expect physical risk to become material within a few years (Krueger et al., 2020), financial institutions might already take action to face it.
- FIs with higher exposure to physical risk engage in various initiatives to reduce their environmental footprints.

VARIABLES	(1) ResourceScore	(2) Environmental Team	(3) Environmental Products	(4) Climate Scenario Analysis	(5) Supplier Climate Engagement
$\hat{\beta}_{VMS}$ (t-1)	1.131*	0.123***	0.0979***	0.0958*	0.533***
	(0.615)	(0.0427)	(0.0349)	(0.0502)	(0.174)
Constant	-70.37***	-3.704***	-5.524***	-4.075***	-6.687***
	(10.55)	(0.660)	(0.748)	(0.800)	(2.005)
Observations	1,273	1,256	1,341	757	353
R-squared	0.566				
Adjusted R-squared	0.482				
Controls	Yes	Yes	Yes	Yes	Yes
Country-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Industry-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes

ROBUSTNESS TESTS (I)

- Use alternative climate risk factors (L/S portfolios based on different characteristics).
  - Transition risk factors: 90% correlation based on Scope 1 (reported) only vs. Scopes 1 + 2 (estimated & reported)
  - Physical risk factors: Only 26% correlation on average between the factors based on Trucost, ISS-ESG and Carbone4

$\Rightarrow$ Large disagreement between physical scores that can lead to dispersion in investment flows, limiting or delaying the incorporation of physical risks into asset prices (see Billio et al., 2021 for ESG scores).

The results remain non-significant based on each physical risk score.

ROBUSTNESS TESTS (II)

- Placebo test
  - Rebuild systemic risk indicator & climate factors using 1990-2005 data.
  - Since climate data is unavailable over the period, we use the average of of climate characteristics from 2005 to 2022 to sort non-financial firms into portfolios.
  - **We find non-significant and negative effects of both transition and physical risks on systemic risk.**

CONCLUSION

- We build a market-based framework to:
  - identify the FIs most exposed to tail climate risks
  - detect potential contagion effects arising from climate risks

- We find that transition risk affects systemic risk, while physical risk does not.

- FIs that are less exposed to transition risks have:
  - lower Scope3 emissions, reliable emission data/emission reduction pathways
  - long-term orientation

- Our framework is flexible :
  - It can be used to dynamically monitor whether the effect of climate risks on financial stability is becoming a growing concern from an investor perspective
  - It can be used on other countries, sectors, asset types and periods.
  - It can be used to assess other types of emerging risk for financial stability.

Thank you for your attention!

Any feedback is highly welcome

The paper is available on SSRN:

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APPENDIX – DYNAMIC VaR ESTIMATION

- The VaR is the estimated loss of a financial institution that, within a given period, will not be exceeded with a certain probability θ:

$$prob[return_t < -VaR_t | \, \Omega_t] = \theta$$

- The VaR can be estimated dynamically:

$$\widehat{VaR}_{i,t} = \hat{\mu}_{i,t} + \hat{\sigma}_{i,t|t-1} F(1-\theta)^{-1}$$

where $\hat{\sigma}_{i,t|t-1}$ is the conditional standard deviation given the information at $t-1$, F^{-1} is the inverse probability density function of a pre-specified distribution and $\hat{\mu}_{i,t}$ is the mean returns of institution *i* at time *t*.

- Following Kuester et al. (2006), we model $\hat{\sigma}_{i,t}$ by extracting the conditional standard deviation from a GARCH model. We apply the threshold GARCH model of Glosten et al. (1993):

$$\hat{\sigma}^2_{i,t} = \omega + (\alpha + \gamma \mathbb{I}_{t-1})\varepsilon^2_{t-1} + \beta \hat{\sigma}^2_{i,t-1}$$

$$\mathbb{I}_{t-1} = \begin{cases} 0, & r_{t-1} < \mu \\ 1, & r_{t-1} \geq \mu \end{cases}$$

All the parameters (μ, ω, α, γ, and β) are estimated simultaneously, by maximizing the log-likelihood.

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APPENDIX – CLIMATE RISK FACTORS

- We build factor-mimicking portfolios (Fama and French, 1993) based on climate characteristics:
  - Transition risk: Carbon emission intensity (Scope 1 & 2 divided by net sales)
  - Physical risk: Trucost physical climate risk scores based on seven hazards (coldwave, flood, heatwave, hurricane, sea-level rise, water stress, wildfire) using a 2050-horizon moderate-intensity climate change scenario.

- At each period, we sort *non-financial* firms into 5 portfolios based on quintile of climate characteristics.

- To mitigate correlation with existing factors, the transition risk factor is constructed using six value-weighted portfolios formed on market capitalization, book-to-market, and the two lowest and highest deciles of carbon emissions

$$BMG_t = \frac{LB_t + HB_t + SB_t + BB_t}{4} - \frac{LG_t + HG_t + SG_t + BG_t}{4}$$

- As correlation with HML is “naturally” low, the physical climate factor is built using four value-weighted portfolios formed on size and the two lowest and highest deciles of Trucost physical scores

$$VMS_t = \frac{SV_t + BV_t}{2} - \frac{SS_t + BS_t}{2}$$

- Since we are interested in extreme climate risk, we estimate the VaR of each climate risk factor.

APPENDIX – BMG PORTFOLIOS

Sectors	Number of firms		% in portfolio		Average market capitalization (in million euros)		Average CO2 emissions (scopes 1 & 2), in tons		Average carbon intensity (Ratio of scope 1 & 2 emissions to sales)	
	Low climate risk	High climate risk	Low climate risk	High climate risk	Low climate risk	High climate risk	Low climate risk	High climate risk	Low climate risk	High climate risk
Aerospace and Def.	1	1	0.0%	0.2%	222	4,708	700	164,478	0.42%	655%
Alternative Energy	5	6	0.6%	0.1%	3,035	327	10,856	389,836	0.27%	1105%
Automobiles		3		0.2%		1,626		446,032		22%
Beverages	1	1	0.1%	0.0%	2,471	593	88	70,292	0.02%	15%
Chemicals	1	27	0.3%	7.5%	8,810	7,792	11,664	4,024,673	0.34%	65%
Construction and Mat.	7	15	0.1%	2.2%	491	4,069	4,038	2,551,726	0.34%	145%
Electricity	3	31	0.1%	14.1%	1,017	12,818	107	11,585,986	0.10%	147%
Electronic Equipment	7	1	0.2%	0.1%	654	1,935	1,881	485,900	0.39%	41%
Fixed Line Telecom.	7	6	1.5%	0.6%	5,683	2,886	10,713	410,112	0.30%	40%
Food and Drug Retail	6		1.0%		4,228		10,285		0.27%	
Food Producers		19		2.2%		3,202		6,839,202		610%
Forestry and Paper	1	14	0.0%	1.7%	181	3,460	0	1,237,697	0.00%	59%
Gas, Water	1	12	0.0%	7.4%	740	17,428	1,842	24,236,625	0.51%	118%
General Industrials	2	18	0.3%	1.9%	3,294	2,927	7,725	2,668,725	0.49%	52%
General Retailers	38	2	4.8%	0.0%	3,308	575	10,776	174,412	0.27%	21%
Health Care	12	5	1.7%	0.6%	3,626	3,465	2,760	183,066	0.29%	38%
Household Goods	9	2	0.7%	0.1%	2,034	710	5,293	174,499	0.31%	27%
Industrial Engineering	3	2	0.6%	0.1%	4,957	725	26,792	249,862	0.35%	33%
Metals and Mining		19		2.7%		4,066		13,357,855		12,425%
Industrial Transport.	6	28	1.4%	3.8%	6,606	3,783	36,081	2,621,499	0.34%	181%
Leisure Goods	4		0.2%		1,211		819		0.24%	
Media	33	1	5.8%	1.3%	4,559	35,388	7,286	114,084	0.29%	37%
Mining		35		13.4%		10,782		3,941,549		2,424%
Oil and Gas Prod.		41		24.9%		17,112		7,072,139		121%
Oil Equipment	2	18	0.2%	1.9%	2,639	2,937	290	1,069,231	0.10%	113%
Personal Goods	13	3	25.5%	0.1%	50,977	554	44,366	963,673	0.29%	29%
Pharmaceuticals	12	9	9.4%	1.9%	20,230	5,827	8,767	100,642	0.22%	62%
Software	105	4	15.5%	0.1%	3,823	1,020	3,324	1,241,990	0.31%	1138%
Support Services	22	6	1.9%	0.4%	2,262	1,793	8,700	574,565	0.23%	53%
Technology Hardware	14	3	2.2%	0.1%	4,061	1,328	11,540	217,997	0.27%	34%
Travel and Leisure	15	30	1.9%	3.4%	3,240	3,185	7,804	2,677,820	0.25%	105%
Unclassified	80	48	24.1%	7.2%	7,804	4,247	6,760	8,382,608	0.26%	204%
Total	410	410	100%	100%	6,331	6,866	8,136	5,539,677	0.28%	934%

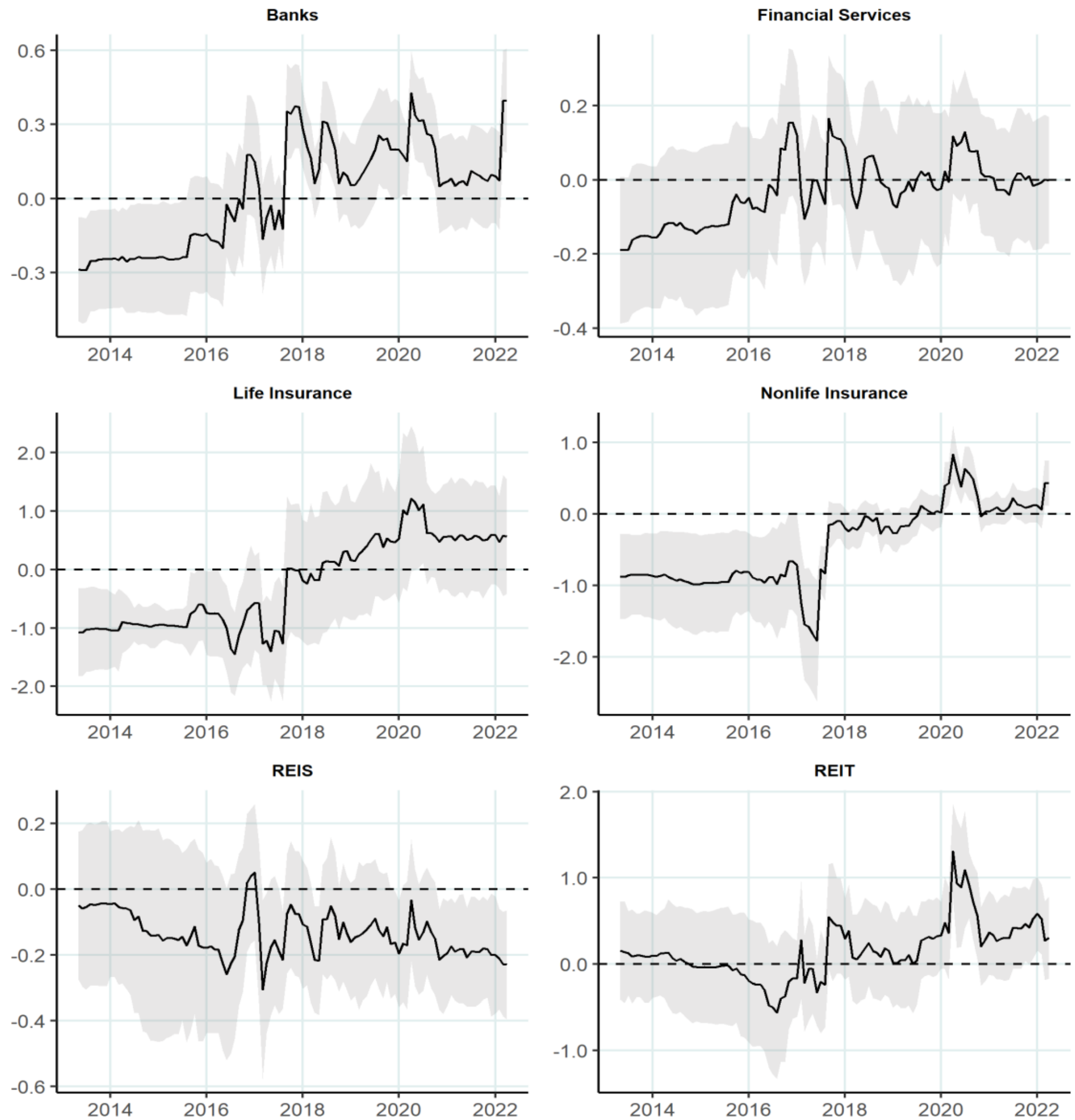
APPENDIX – VMS PORTFOLIOS

Sector	Number of stocks		% of portfolio		Average market capitalization (in million euros)		Average physical score (moderate 2050)	
	Low climate risk	High climate risk	Low climate risk	High climate risk	Low climate risk	High climate risk	Low climate risk	High climate risk
Aerospace and Defense	2	7	0.9%	1.5%	2,319	5,305	30.5	61.9
Alternative Energy	4	6	0.6%	0.0%	785	138	34.5	67.3
Automobiles and Parts	6	2	1.2%	0.0%	995	144	33.0	71.0
Beverages	8	3	2.6%	0.7%	1,606	5,267	33.1	62.0
Chemicals	7	10	0.9%	4.2%	619	10,147	33.6	62.2
Construction and Materials	18	16	2.4%	1.1%	659	1,640	33.0	61.6
Electricity	5	2	0.3%	0.7%	261	7,948	31.8	62.0
Electronic and Electrical Equipment	5	3	1.0%	0.0%	1,022	320	31.0	68.0
Fixed Line Telecommunications	4	5	2.0%	1.2%	2,490	5,601	28.5	60.6
Food and Drug Retailers	4	3	1.7%	0.1%	2,161	690	32.8	62.7
Food Producers	18	15	6.9%	0.5%	1,903	834	31.8	64.3
Forestry and Paper	5	3	2.5%	0.2%	2,455	1,404	32.4	61.3
Gas, Water and Multiutilities		3		0.4%		3,544		62.7
General Industrials	13	11	1.2%	1.0%	473	2,193	32.2	63.5
General Retailers	21	6	5.8%	0.0%	1,354	170	32.7	61.3
Health Care Equipment and Services	17	11	4.1%	3.4%	1,197	7,343	32.8	60.2
Household Goods and Home Construction	16	7	3.6%	0.4%	1,126	1,360	33.0	61.9
Industrial Engineering	12	6	3.0%	0.6%	1,227	2,576	33.5	62.7
Industrial Metals and Mining	7	4	0.8%	0.1%	598	725	30.4	63.0
Industrial Transportation	15	16	14.6%	4.1%	4,799	6,189	32.7	64.4
Leisure Goods	6	5	0.2%	0.3%	202	1,431	31.8	62.0
Media	4	24	0.1%	4.1%	85	4,101	29.8	62.1
Mining	15	21	0.3%	0.1%	105	103	31.7	63.0
Oil and Gas Producers	11	9	2.9%	10.8%	1,321	28,821	33.0	64.0
Oil Equipment and Services	7	6	0.4%	0.2%	292	809	30.3	65.7
Personal Goods	3	7	1.0%	0.5%	1,691	1,868	35.0	64.3
Pharmaceuticals and Biotechnology	39	25	7.4%	12.3%	941	11,777	31.3	62.2
Software and Computer Services	31	37	4.3%	7.8%	687	5,072	30.8	61.1
Support Services	11	16	1.7%	4.3%	772	6,406	33.9	62.0
Technology Hardware and Equipment	25	16	2.2%	3.9%	427	5,875	32.1	61.8
Travel and Leisure	12	22	5.9%	2.4%	2,432	2,612	32.1	61.2
Unclassified	89	92	17.2%	32.9%	954	8,565	31.2	62.1
Total	440	419	100%	100%	1,123	5,723	32.0	62.4

APPENDIX – FACTOR CORRELATION

	BMG	VMS	MKT	SMB	HML	RMW	CMA	WML	RR	ML	DP	YC	NS
VMS	-5%												
MKT	0%	25%											
SMB	10%	15%	25%										
HML	-22%	13%	37%	33%									
RMW	-1%	10%	31%	15%	47%								
CMA	19%	17%	32%	23%	-2%	15%							
WML	21%	26%	26%	15%	21%	22%	17%						
RR	4%	0%	-2%	-1%	-14%	-11%	11%	-11%					
ML	-5%	12%	29%	27%	11%	33%	13%	12%	-13%				
DP	-3%	26%	80%	41%	41%	38%	29%	32%	-1%	39%			
YC	-4%	1%	3%	-4%	4%	2%	1%	5%	5%	12%	8%		
NS	-6%	9%	16%	-2%	17%	-4%	1%	8%	6%	3%	7%	27%	
ES	-7%	13%	47%	46%	63%	12%	12%	19%	4%	7%	47%	1%	17%

APPENDIX – PHYSICAL RISK BY FINANCIAL INDUSTRY



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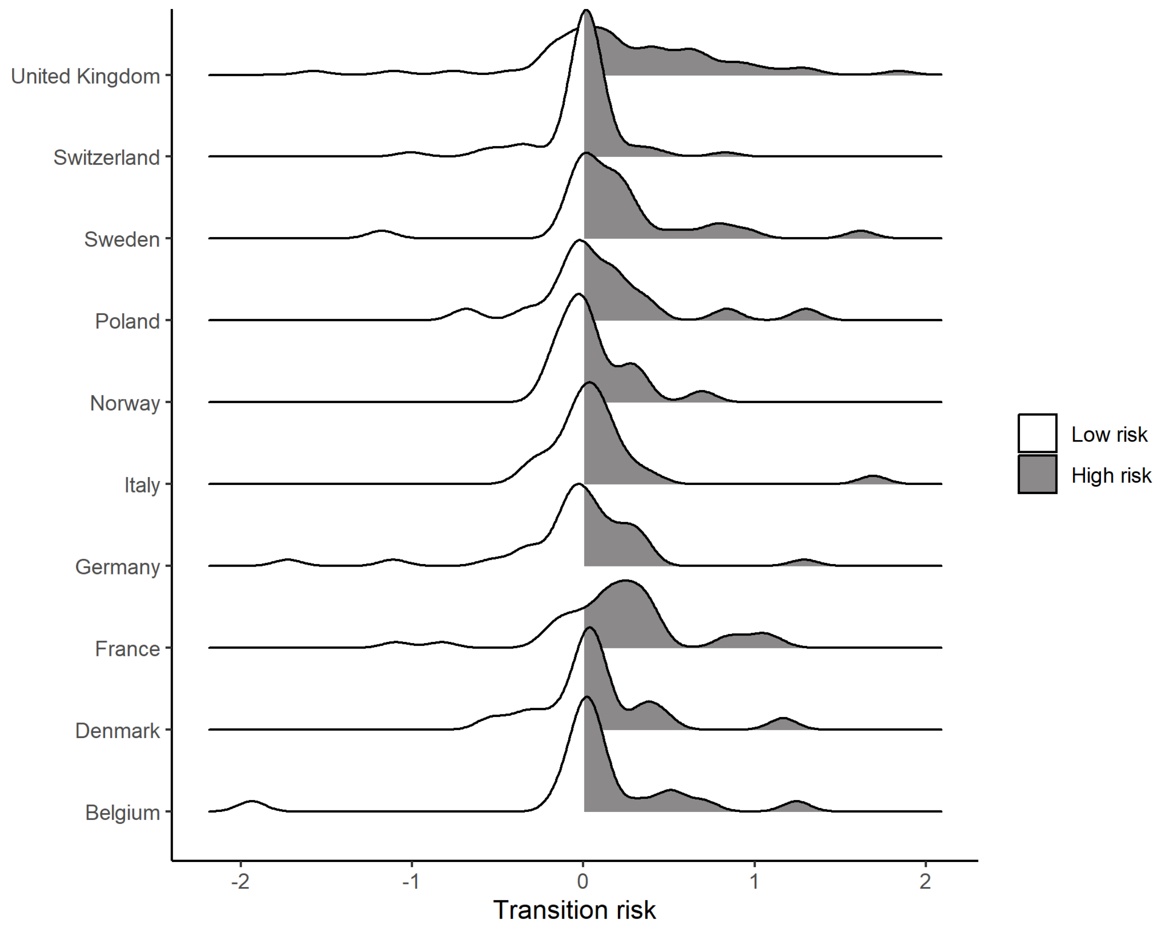
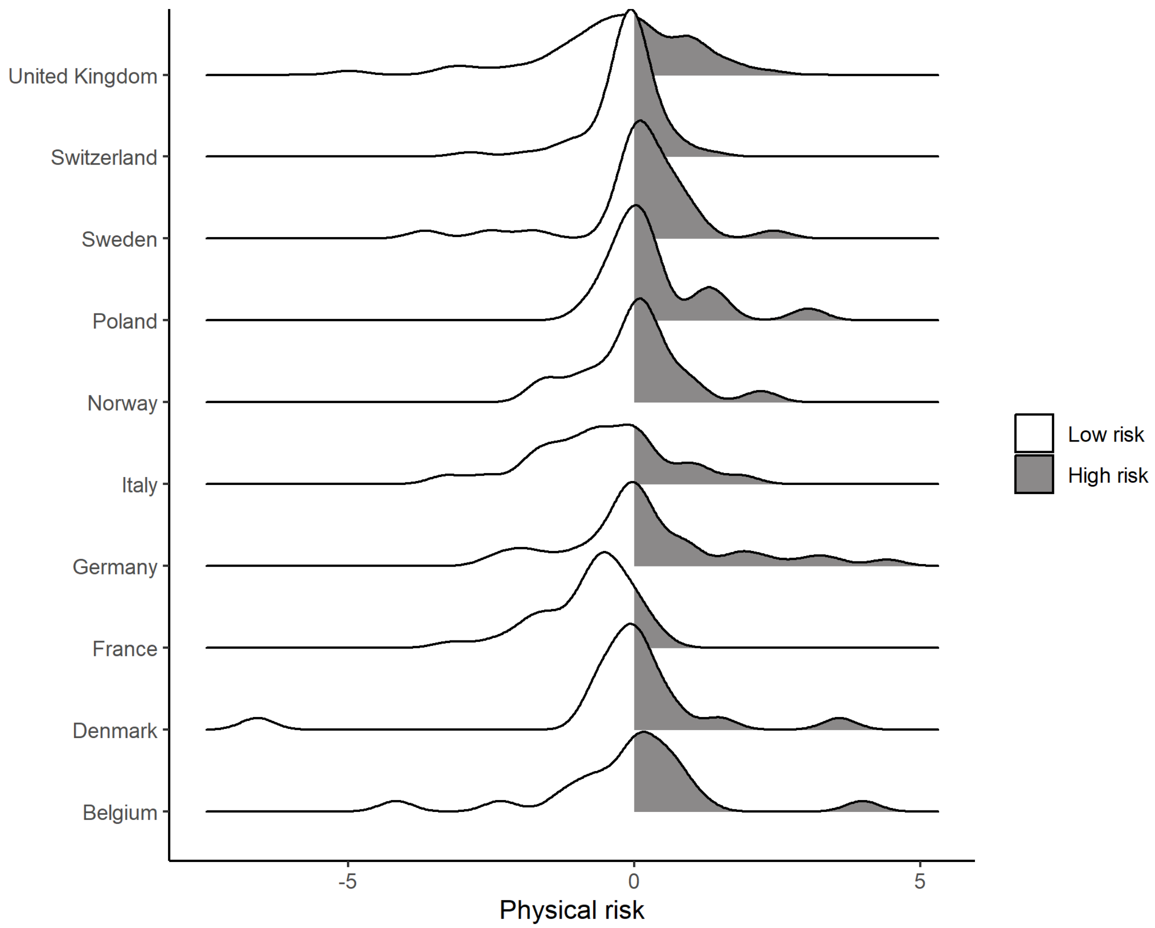
APPENDIX – TRANSITION RISK BY COUNTRY



APPENDIX – PHYSICAL RISK BY COUNTRY



APPENDIX – OTHER FACTORS DESCRIPTION (I)

Variable	Description
CMA	Difference between the returns on portfolios of low and high investment stocks (Conservative-Minus-Aggressive factor), based on the change in total assets divided by total assets from Kenneth French website library.
DP	Default premium computed as the spread between the ICE high yield euro corporate rates against the 3-month Euribor rate (Fred database).
EG	Difference between the returns of portfolios of high and low expected growth stocks (Expected Growth factor) from Hou-Xue-Zhang q-factors data library.
ES	Economic Sentiment indicator (Eurostat).
HML	Difference between the returns on portfolios of high and low book-to-market stocks (High-Minus-Low factor) from Kenneth French website library.
IA	Difference between the returns on portfolios of high and low investment-to-assets stocks (Investment/Assets factor) from Hou-Xue-Zhang q-factors data library.
LIQ	Non-traded liquidity factor of Pastor and Stambaugh (2003) from https://faculty.chicagobooth.edu/lubos-pastor/data
ME	Difference between the returns on portfolios of small and large stocks from Hou-Xue-Zhang q-factors data library.
MKT	Difference between the returns on the market portfolio and the risk-free rate (Market factor) from Kenneth French website library.

APPENDIX – OTHER FACTORS DESCRIPTION (II)

Variable	Description
ML	Interbank Market Liquidity indicator, calculated as the spread between the 3-month Euribor rate against the equivalent Overnight Indexed Swap rate.
NS	North-South spread, computed as the difference between the 10-year German sovereign bond rate against an average of Greece, Ireland, Italy, Spain, and Portugal 10-year rates (European Central Bank).
QMJ	Quality-Minus-Junk (QMJ) factor that invests long quality stocks and shorts junk stocks (Asness et al., 2014) from the AQR library.
RMW	Difference between the returns of robust and weak stocks (Robust-Minus-Weak factor), based on operational profitability (revenues divided by book equity) from Kenneth French website library.
ROE	Difference between the returns on portfolios of high and low profitability stocks (Return on Equity factor), based on the income before extraordinary items divided by one-quarter-lagged book equity; from Hou-Xue-Zhang q-factors data library.
RR	Risk Reversal on the USD/EUR options from Bloomberg.
SMB	Difference between the returns on portfolios of small and large stocks (Small-Minus-Big factor) from Kenneth French website library.
WML	Difference between the returns on portfolios of past winner and past loser stocks (Momentum factor) from Kenneth French website library.
YC	Yield Curve indicator, computed as the spread between 10-year and 2-year Euro Area composite rates (European Central Bank).

APPENDIX – OTHER VARIABLE DESCRIPTION (II)

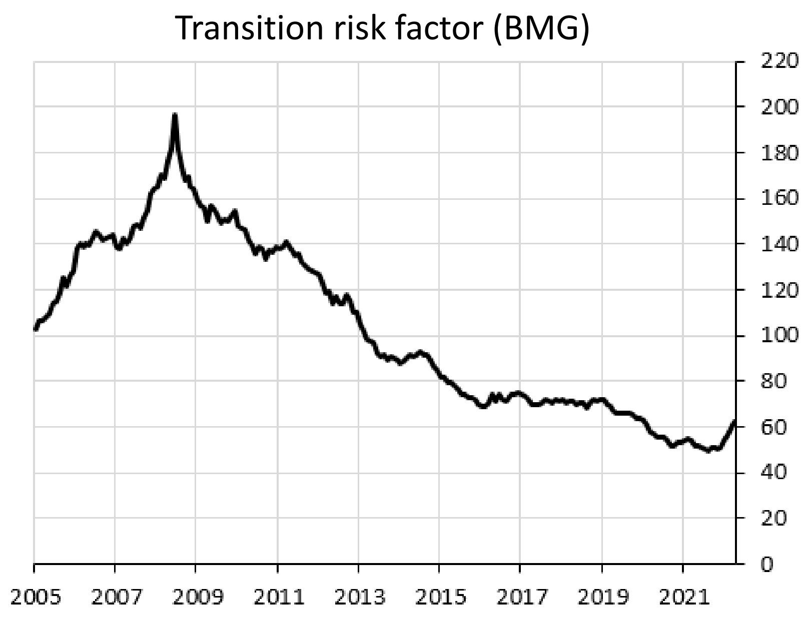
Variable	Description
Beta	Equity beta (897E in Datastream).
Board LT incentives	Dummy variable equal to one if board members have long-term compensation incentives (from CGCPDP052 in Refinitiv ESG).
Cash	Ratio of cash (item WC02005 in Worldscope Datastream) to total assets (item WC02999 in Worldscope Datastream).
ClimateScenarioAnalysis	Dummy variable equal to one if the financial institution has conducted a climate scenario analysis for its portfolio of financial assets (CLIMATE_SCENARIO_ANALYSIS in Bloomberg).
DiscussClimateRisk	Dummy variable equal to one if the Management Discussion and Analysis (MD&A) or its equivalent risk section of the financial institution's annual report discusses business risks related to climate change (CLIMATE_RISKS in Bloomberg).
Environmental Dislosure Score	Score based on the extent of a company's Environmental disclosure (ENVIRONMENTAL_PILLAR_DISCLOSURE in Bloomberg).
EnvironmentalProducts	Dummy variable equal to one if the financial institution has at least one product line or service that is designed to have positive effects on the environment (item ENPIDP019 in Datastream).
EnvironmentalTeam	Dummy variable equal to one if the financial institution has an environmental management team (item ENRRDP004 in Datastream).
ESG Disclosure Score	Score based on the extent of a company's Environmental, Social, and Governance (ESG) disclosure (ESG_DISCLOSURE_SCORE in Bloomberg).

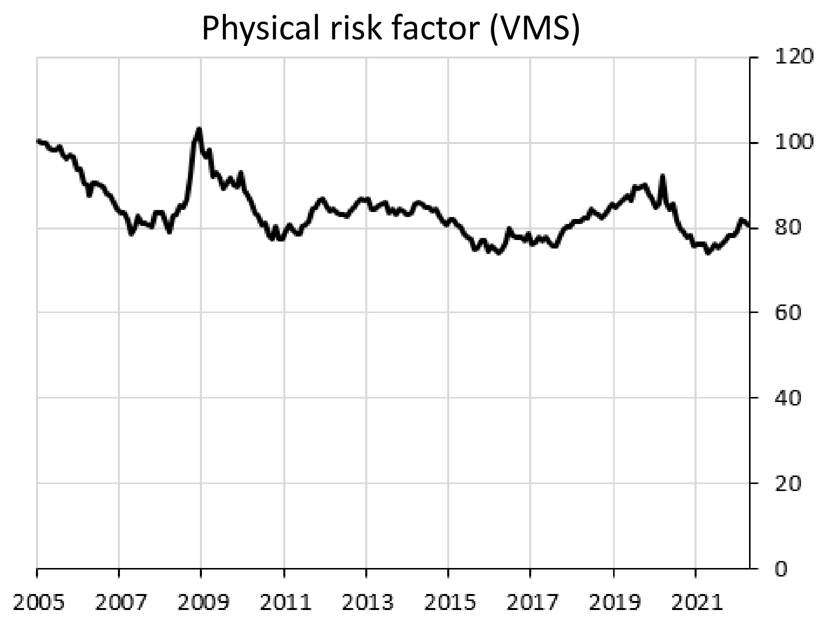
APPENDIX – OTHER VARIABLE DESCRIPTION (II)

Variable	Description
Institutional ownership	Percentage of ownership by banks, insurance, and pension funds (sum of items S_122, S_128, and S_129 from the Securities Holdings Statistics database)
IntegratedStrategy	Dummy variable equal to one if the financial institution integrates extra-financial factors in its management discussion and analysis (MD&A) section in the annual report.
LogCarbonOffsets	Natural logarithm of the equivalent of the CO2 offsets, credits, and allowances purchased and/or produced by the financial institution during the year.
LogMarketValue	Natural logarithm of market capitalization (item MV in Datastream, expressed in million euros).
LowScope3intensity	Dummy variable equal to one if the financial institution's Scope3 emissions to revenues (in million USD) ratio is in the bottom quartile (from item in Datastream).
MtoB	Ratio of market value of equity (item MV in Datastream, expressed in million euros) to book value of equity (item WC03501 in Worldscope Datastream, expressed in thousand euros), multiplied by 1,000.
NetIncome	Ratio of net income (item WC01751 in Worldscope Datastream) to total assets (item WC02999).
PolicyEngagement	Dummy variable equal to one if the financial institution engages with policymakers on possible responses to climate change (from CDP).
ReductionTargetReached	Dummy variable equal to one if the financial institution has reached or completed an emissions reduction target during the year (from CDP).
ResourceScore	Resource score, reflecting the financial institution's performance and capacity to reduce the use of materials, energy, or water, and to find more eco-efficient solutions (item TRESGENRRS in Datastream).
SupplierClimateEngagement	Dummy variable equal to one if the financial institution engages with its suppliers on climate change issues (from CDP).
VerifiedScope3	Dummy variable equal to one if all of the financial institution's Scope 3 emissions have been verified by a third party (from CDP).

APPENDIX : THE FRAMEWORK – STEP II

- **Cumulative returns of the climate risk factors**





APPENDIX : THE FRAMEWORK – STEP II

- **Are these factors reflected in the returns of non-financial equities?**

Panel A: Effect of the transition risk factor (BMG) on 10 portfolios based on carbon intensity

	Portfolios based on carbon intensity									
	q1	q2	q3	q4	q5	q6	q7	q8	q9	q10
BMG	-0.476***	-0.234***	-0.160*	-0.186**	-0.083	-0.118*	-0.026	0.167**	0.352***	0.474***
	(0.066)	(0.078)	(0.097)	(0.087)	(0.083)	(0.067)	(0.066)	(0.068)	(0.067)	(0.068)
Observations	208	208	208	208	208	208	208	208	208	208
R^2	0.765	0.659	0.626	0.666	0.624	0.649	0.688	0.727	0.769	0.819
Adjusted R^2	0.757	0.648	0.613	0.654	0.611	0.636	0.677	0.717	0.761	0.813
Control 6FF	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: Effect of the physical risk factor (VMS) on 10 portfolios based on physical risk scores

	Portfolios based on physical risk exposure									
	q1	q2	q3	q4	q5	q6	q7	q8	q9	q10
VMS	0.812***	0.143	0.067	0.150**	0.026	0.125	0.063	0.032	0.128**	-0.432**
	(0.119)	(0.115)	(0.077)	(0.075)	(0.069)	(0.092)	(0.081)	(0.112)	(0.062)	(0.203)
Observations	208	208	208	208	208	208	208	208	208	208
R^2	0.760	0.677	0.676	0.744	0.781	0.654	0.675	0.650	0.603	0.611
Adjusted R^2	0.751	0.665	0.665	0.735	0.773	0.642	0.663	0.638	0.589	0.597
Control 6FF	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

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